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COLLEGE OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Radiation Laboratory

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Thomas B.A. Senior

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The main themes of the work have been the analytical and numerical study of the scattering of electromagnetic waves in various configurations, and the low frequency scattering from a number of different types of particles. In large measure the analytical work is approaching a natural conclusion and our understanding of the scattering properties of sheets is now almost sufficient for the design of a variety of section shapes incorporating them. For a resistive strip, for which it was earlier shown that the bistatic scattered field can be expressed in terms of the current induced in the corresponding half plane, (CONTINUED)			

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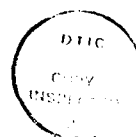
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ITEM #10, CONTINUED: and the the resulting (uniform) high frequency asymptotic expansion gives accurate results even for strip widths which are a small fraction of a wavelength. An efficient procedure for computing the half plane current for any (complex) resistivity has now been developed.

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The two main themes of the work have been the analytical and numerical study of resistive sheets in various configurations, and the low frequency scattering from a number of different types of particles. In large measure the resistive sheet work is approaching a natural conclusion and our understanding of the scattering properties of sheets is now almost sufficient for the design of low cross section shapes incorporating them. For a resistive strip or ribbon it was earlier shown (Senior, 1979) that the bistatic scattered field can be expressed in terms of the current induced in the corresponding half plane, and that the resulting (uniform) high frequency asymptotic expression gives accurate results even for strip widths which are a small fraction of a wavelength. An efficient procedure for computing the half plane current for any (complex) resistivity has now been developed [2].

For the problem of a wedge consisting of two resistive sheets meeting at an angle, there is still no exact closed form solution available. Because of the non-zero field inside the wedge, methods such as those of Maliuzhinets (1959) and Kontorovich-Lebedev (1939) generate functional difference equations which cannot be solved using standard techniques, but we have recently developed a novel procedure which replaces the equations by integral equations of the Fredholm type. These equations are well understood in the literature. Though exact solutions have not been found, approximate solutions have been obtained from linear operator theory via the method of successive approximation. The resulting solutions are in the form of power series in the resistivity, and bounds on the region of convergence are given.

This work has been published as a technical report [6] and is the Ph.D. thesis of Mr. I. J. LaHaie.

For the numerical solution of scattering problems involving resistive strips and plates, an alternative to the moment method applied to the integral equation(s) for the surface fields is the finite element technique. The technique has been applied to the scattering problem of a resistive strip, and results obtained for a variety of resistivities and strip widths. A key objective is to test the efficiency of this approach vis-a-vis the moment method, and these tests are now underway. It is anticipated that this work will constitute the Ph.D. thesis of Mr. J. L. Mason, and has been carried on with minimal support from the present Grant.

In practice, any resistive sheet structure has all of its dimensions finite, and a knowledge of the scattering from a resistive strip provides only a limited amount of information about the scattering from a plate. Because of this, a problem of considerable practical interest and importance has been the development of a numerical procedure for solving the scattering problem for a polygonal resistive plate. We have now succeeded. One aspect of the formulation is the use of the Stratton-Chu representation (equivalent to vector and scalar potentials) in place of the more standard Franz representation to reduce the order of the singularities involved. This has been justified by proving [5] that the two representations are equivalent under all circumstances, and that the Kottler line integrals which, in principle, distinguish the two for an open structure are, in fact, null integrals regardless of the boundary condition involved. The program is described in the Ph.D. thesis of Mr. M. Naor (1981), and the data obtained are

in excellent agreement with experiment. We regard this work as a significant achievement, and though there are still some improvements that can (and should) be made in the computer program, e.g., to eliminate the present restriction to rectangular cells and to increase the overall size of plates that can be handled, the scattering problem for a plate of any resistivity has now passed from the 'research' to the 'development' stage.

As part of this work, we have also examined the low frequency scattering behavior of perfectly conducting and (uniform) resistive plates [3,4]. For the metallic plate, the electric dipole has components only parallel to the plate and the magnetic dipole has just a single component normal. The corresponding elements of the polarizability tensors are expressed as weighted integrals of certain potential functions. Integral equations are developed from which the potentials can be obtained, and using the numerical techniques referred to above, programs have been written to solve these equations (Naor and Senior, 1981). What is more, from a knowledge of the magnetostatic potential alone, the next term in the low frequency expansion can be found, and an explicit expression has been derived [3]. For a resistive plate there is no magnetic dipole contribution, and the electric dipole is identical to that for the corresponding perfectly conducting plate. The resistivity appears explicitly in the next term in the low frequency expansion, and it has been shown [4] that this can also be expressed in terms of potentials analogous to the zeroth order ones. The manner in which the resistivity appears makes evident the discontinuity in the expansion as the resistivity becomes zero.

The above work is a natural bridge to our continuing investigation of low frequency scattering by particles typical of those occurring in the atmosphere. Most atmospheric scattering and absorption studies to date have employed 'equivalent' spheres to simulate the particles, but there is a growing realization that spheres are not adequate to reveal the detailed features of the phenomena that occur. At low frequencies, however, it is not too hard to determine the scattering from particles of more realistic shape. Analytical expressions are available for the elements of the polarizability tensor for ellipsoids and spheroids, and a computer program has been developed for rectangular parallelepipeds of square cross section (Herrick and Senior, 1977). An even more realistic shape is a rod of hexagonal cross section. For this also a program has been written, and data will appear in Mr. D. F. Herrick's forthcoming Ph.D. thesis.

To find the scattering and absorption by a distribution of one (or more) species of particle, the customary procedure is to incorporate the single particle scattering into a radiative transfer program, thereby accounting for multiple scattering effects. An alternative approach is to treat the assembly as an artificial dielectric and to compute the attenuation coefficient from a knowledge of the effective (tensor) permittivity of the medium. For a sparse distribution of N identical, similarly oriented particles such that each 'sees' only the undistorted incident field, the resulting absorption is simply N times the absorption cross section of each particle. With a denser distribution, a self-consistent formulation in which the local field is modified by the (first order) scattering from the rest of the

particles is provided by a generalized version of the classical Clausius-Mossotti expression in which the excluded volume is taken congruent to the particle in question. Although this is still, in part, a single scattering theory, the results are consistent for all densities of particles [7].

Publications Resulting from Present Year's Grant

- T.B.A. Senior, "Approximate boundary conditions," (mini-review), IEEE Trans. Antennas and Propagat. 29 (5), 826-829.
- T.B.A. Senior, "The current induced in a resistive half plane," Radio Sci. 16 (6), 1249-1254.
- T.B.A. Senior and M. Naor, "Low frequency scattering by a metal plate," accepted for publication in Radio Sci.
- T.B.A. Senior, "Absorption by a distribution of dielectric particles," paper presented at the National Radio Science Meeting, Boulder, CO, January 1981.

Cumulative list of publications resulting from the Grant

A. Journal Articles

- T.B.A. Senior and M. Naor (1981), "Low frequency scattering by a metal plate," accepted for publication in Radio Sci.
- D. F. Herrick and T.B.A. Senior (1977), "Low frequency scattering by rectangular dielectric particles," Appl. Phys. 13, 175-183.
- T.B.A. Senior and H. Weil (1977), "Electromagnetic scattering and absorption by thin-walled dielectric cylinders with application to ice crystals," Appl. Opt. 16, 2970-2985.
- T.B.A. Senior (1978), "Skew incidence on a right-angled impedance wedge," Radio Sci. 13 (4), 639-647.
- T.B.A. Senior (1979a), "Backscattering from resistive strips," IEEE Trans. Antennas Propagat. 27 (6), 808-813.
- T.B.A. Senior (1979b), "Scattering by resistive strips," Radio Sci. 14 (5), pp. 911-924, September-October.
- T.B.A. Senior (1980), "Effect of particle shape on low frequency absorption," Appl. Opt. 19, 2483-2485.
- T.B.A. Senior (1981a), "Approximate boundary conditions" (mini review), IEEE Trans. Antennas and Propagat. 29 (5), 826-829.
- T.B.A. Senior (1981b), "The current induced in a resistive half plane," Radio Sci. 16 (6), 1249-1254.
- T.B.A. Senior and M. Naor (1981), "Low frequency scattering by a resistive plate," submitted for publication in IEEE Trans. Antennas Propagat.

B. Technical Reports

T.B.A. Senior (1977), "Analyses pertaining to the reduction of non-specular scattering," University of Michigan Radiation Laboratory Report NO. 015224-1-T.

I. J. LaHaie (1981), "Function theoretic techniques for the electromagnetic scattering by a resistive wedge," University of Michigan Radiation Laboratory Report No. 015224-2-T.

C. Conference Presentations

T.B.A. Senior (1978b), "Rayleigh scattering," invited talk at XIXth General Assembly of URSI, Helsinki, Finland, 31 July - 8 August; Abstract published in the Digest.

T.B.A. Senior (1978), "Backscattering from resistive strips," talk presented at National Radio Science Meeting, Boulder CO, 6-9 November.

T.B.A. Senior (1979a), "Scattering by resistive strips," talk presented at National Radio Science Meeting, Seattle, WA, 18-22 June.

T.B.A. Senior (1979b), "Scattering by impedance strips," talk presented at National Radio Science Meeting, Boulder, CO, 5-8 November.

T.B.A. Senior (1980), "Scattering by a finite resistive plate," talk presented at the North American Radio Science Meeting, Quebec, Canada, 2-6 June.

T.B.A. Senior and H. Weil (1980), "Particle shapes for maximizing low frequency absorption," Proceedings of the Conference on Obscuration and Aerosol Research, Aberdeen, MD, 21-25 July.

T.B.A. Senior (1981), "Absorption by a distribution of dielectric particles," talk presented at the National Radio Science Meeting, Boulder, CO, 12-15 January.

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